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IMPROVING THE Y-12 NEUTRON
RADIOGRAPHY FACILITY

E. M. Murray
J. L. Telford

UNION
CARBIDE

OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

prepared for the U.S. ATOMIC ENERGY COMMISSION
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Oak Ridge Y-12 Plant

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ABSTRACT

To improve the Y-12 Neutron Radiography Facility, a series of four experiments were conducted. The factors which appeared to be most important for this facility have been identified and the best operating conditions determined. The overall improvement made was quite significant.

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SUMMARY

An experimental program has been conducted to determine the best operating conditions for the Y-12 Neutron Radiography Facility. The program was divided into four experiments: Stage I consisted of an evaluation of the effects of five factors: (1) collimator ratio, (2) beam extraction geometry (the distance in inches the source is moved off the axis of the collimator), (3) bismuth shield (inches), (4) air gap (inches), and (5) moderator (inches). Stage II was concerned with a further evaluation of the same five factors but in a new region which was pointed out by Stage I. Stage III involved an evaluation of the effects of the first three factors: collimator ratio, beam extraction geometry, and bismuth shield. Stage IV was designed to accomplish a fine tuning of the levels of beam extraction geometry and bismuth shield.

Three criteria were observed: (1) Cf/f ratio (density of film with cadmium divided by density of film without cadmium), (2) CRASI (contrast, resolution, and scatter indicator) index, a measure of neutron scatter, and (3) VISQI (visual image, scatter, and quality indicator) faults, a judgement of radiographic resolution.

The important factors for this facility have been identified. The best operating conditions produced significant improvements. It is recommended that a more flexible facility (in terms of radiographic parameters) be established and optimized.

INTRODUCTION

A neutron radiography facility was installed and operating in the Oak Ridge Y-12 Plant^(a) by November 1971. Figure 1 provides a view of the complete facility. Neutrons are emitted by a 10-milligram source of californium-252. Thermal neutrons are, in turn, produced in a one-foot cube of high-density polyethylene surrounding the neutron source, seen to the left of center in Figure 2. A gadolinium vacuum-deposited screen was used in conjunction with Kodak AA film in a vacuum cassette. The screen and cassette are shown in Figure 3. All collimators used are internally coated with boron. The collimators can be seen in Figure 4.

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Figure 1. NEUTRON RADIOGRAPHY FACILITY.

(a) Operated for the US Atomic Energy Commission by the Union Carbide Corporation's Nuclear Division.

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Figure 2. POLYETHYLENE CUBE CONTAINING THE NEUTRON SOURCE.

142801

Figure 3. GADOLINIUM SCREEN AND CASSETTE.

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Figure 4. SOURCE COLLIMATORS.

This experimental program was designed to determine the best operating conditions. The program was divided into four experiments (stages). In order to obtain the most information per unit of time spent, Stages I and II were statistical designs known as fractional factorials; Stages III and IV were full factorials.

Five factors were of interest. The factors and their restrictions were:

1. Collimator Ratio - three collimators with fixed ratios.
2. Beam Extraction Geometry (source position) - highly adjustable in one direction.
3. Air Gap - a physical range from zero to three inches.
4. Moderator Shield (bismuth) - a physical range from zero to three inches.
5. Moderator Gap - a physical range from zero to three inches.

It was desired to observe three criteria: (1) Cf/f ratio (the density of film with cadmium divided by density of film without cadmium; (2) CRASI (contrast, resolution, and scatter indicator), and (3) VISQI (visual image, scatter, and quality indicator), a judgement of radiographic resolution.

RADIOGRAPHY FACILITY EVALUATION

STAGE I - SCREENING

The factors investigated in the first step were adjustable and thought to have some effect on the observed response.

The two levels of each factor that were explored in the first stage are listed in Table 1.

Table 1
FACTORS EXPLORED IN STAGE I

Factors	Levels	
	Low	High
Collimator Ratio	14.3	25.0
Source Position (inches off axis)	0	2.0
Bismuth Shield (inches)	0	0.5
Air Gap (inches)	0	3.0
Moderator (inches)	0	2.0

The factors, or interaction of factors, which had a significant effect on Cf/f were: (1) interaction of the collimator ratio with the air gap, and (2) interaction of the source position with the moderator. These interactions of factors are illustrated in Figure 5.

To interpret the graph of Figure 5, picture a hillside across each graph (perpendicular to the plane of the graph). The average Cf/f value is the altitude at that point on the hillside. A minimum value for Cf/f is desired. The arrows are pointing in the probable direction of the minimum value. This new region was investigated in Stage II.

Figure 5. Cf/f - IMPORTANT FACTORS.

The factors or interaction of factors which had a significant effect on CRASI were: (1) the moderator, (2) interaction of the collimator ratio with the air gap, and (3) interaction of the source position with the bismuth shield.

It was desired to find a maximum value for CRASI. The effect of the moderator was that a larger moderator decreased the CRASI. In Stage II, much smaller thicknesses for the

moderator were investigated. The interactions of factors are illustrated in the graph of Figure 6. The average CRASI value is the altitude at that point on the hillside. The arrows are pointing in the probable direction of the maximum value. This new region was investigated in Stage II.

Figure 6. CRASI INDEX - IMPORTANT FACTORS. (Stage I)

The factors and interactions of factors which had a significant effect on the VISQI were: (1) source position, (2) moderator, (3) interaction of the collimator ratio with the bismuth shield, and (4) interaction of the collimator ratio with the air gap. A minimum value for VISQI was desired. The effect of the source position was to increase VISQI faults as the source position was moved off the axis. The effect of the moderator was an increase of VISQI faults for an increase of the moderator. The interactions of factors are illustrated in Figure 7. As before, the average VISQI value is the altitude at that point on the hillside.

Figure 7. VISQI FAULTS - IMPORTANT FACTORS. (Stage I)

The arrows are pointing to a valley which is the desired location. If the collimator ratio is decreased, the air gap should be increased; and, likewise, the amount of bismuth shield should be increased. Since VISQI is an opinion (not a measurement) it was not valued as much as either Cf/f or CRASI. In Stage II, new levels for all factors were chosen, principally to improve Cf/f and CRASI.

STAGE II - PRELIMINARY TUNING

The two levels of each factor that were explored in Stage II are given in Table 2.

The factors which had a significant effect on Cf/f were: (1) source position, (2) collimator ratio, and (3) bismuth shield. The average Cf/f values for each important factor at high and low levels are listed in Table 3.

This information implies that to improve Cf/f for Stage III, changes should be made that would: move the source position further off the axis, decrease the collimator ratio, and add more bismuth shield.

The interactions of factors which had a significant effect on CRASI were: (1) interaction of the source position with the bismuth shield, and (2) interaction of the air gap with the moderator.

The interactions of factors are illustrated in the graph of Figure 8. Figure 8 should be interpreted as before. The average CRASI value is the altitude at that point on the hillside. The arrows are pointing in the probable direction of the maximum value. In Stage III, a new region for the factors source position and bismuth shield were investigated; a moderator was omitted.

The factor and interactions of factors which had a significant effect on VISQI were: (1) collimator ratio, (2) interaction of the air gap with the bismuth shield, and (3) interaction of the source position with the moderator. The effect of the collimator ratio was to decrease VISQI faults as the collimator ratio was increased, which was opposite to the result for Cf/f. The two interactions of factors are illustrated in Figure 9. Figure 9 should be interpreted as before. For the interaction of the air gap with the bismuth shield, the arrow is pointing in the probable direction of the minimum value; for the interaction of the source position with the moderator, the arrows are pointing out a valley which is the desired location. In Stage III, the levels for the collimator ratio, source position, and bismuth shield factors were chosen principally to improve the Cf/f and CRASI.

Table 2
FACTORS EXPLORED IN STAGE II

Factors	Levels	
	Low	High
Collimator Ratio	14.3	18.2
Source Position (inches off axis)	0.5	1.5
Bismuth Shield (inches)	0.5	1.0
Air Gap (inches)	1.5	3.0
Moderator (inches)	0	0.5

Table 3
IMPORTANT FACTORS - Cf/f -
STAGE II
(Average Cf/f Values - Minimize)

Factors	Levels	
	Low	High
Source Position	0.747	0.709
Collimator Ratio	0.721	0.736
Bismuth Shield	0.741	0.716

Figure 8. CRASI INDEX - IMPORTANT FACTORS. (Stage II)

Figure 9. VISQI FAULTS - IMPORTANT FACTORS. (Stage II)

STAGE III - TUNING

The two levels of each factor that were explored in Stage III are given in Table 4.

The moderator was omitted and the air gap was set at one and one-half inches.

Table 4
FACTORS EXPLORED IN STAGE III

Factors	Levels	
	Low	High
Collimator Ratio	14.3	18.2
Source Position (inches off the axis)	1.0	2.0
Bismuth Shield (inches)	1.25	1.50

The factors which had a significant effect on Cf/f were: (1) source position, (2) collimator ratio, and (3) bismuth shield. The average Cf/f value for each factor at high and low levels is listed in Table 5.

To improve Cf/f, the bismuth shield should be increased and the source positions of one and one and one-half inches explored (considering Tables 2 and 4).

The interaction of factors which had a significant effect on CRASI was the interaction of the source position with the collimator ratio. The average CRASI values for each combination of these two factors are summarized in Table 6.

The factor which had a significant effect on VISQI was the source position. The effect of the source position was to increase VISQI as the source was moved away from the axis.

STAGE IV - FINE TUNING

In Stage IV, the factors of source position and bismuth shield were explored.

The levels of each factor that were explored in Stage IV are reported in Table 7.

Table 7
FACTORS EXPLORED IN STAGE IV

Factors	Levels	
	Low	High
<u>Step 1</u>		
Source Position (inches)	1.0	1.5
Bismuth Shield (inches)	1.75	2.25
<u>Step 2</u>		
Source Position (inches)	1.0	1.5
Bismuth Shield (inches)	2.25	2.75

Table 8
IMPORTANT FACTORS - Cf/f - STAGE IV
(Cf/f Values - Minimize)

Source Position (inches)	Bismuth Shield (inches)		
	1.75	2.25	2.75
1.0	0.676	0.658	0.669
1.5	0.659	0.672	0.679

Table 5
IMPORTANT FACTORS - Cf/f - STAGE III
(Average Cf/f Values - Minimize)

Factors	Levels	
	Low	High
Source Position	0.699	0.731
Collimator Ratio	0.705	0.726
Bismuth Shield	0.721	0.710

Table 6
IMPORTANT FACTORS - CRASI - STAGE III
(Average CRASI Values - Maximize)

Source Positions (inches)	Collimator Ratios	
	14.3	18.2
1.0	48.2	44.3
2.0	43.0	35.0

The moderator was omitted, the air gap was set at one and one-half inches, and the collimator ratio was set at 14.3.

The results of this fine tuning was that for both Cf/f and CRASI the best results were obtained with the source position one inch off the axis and with two and one-quarter inches of bismuth shield. The results of Stage IV are recorded in Tables 8 and 9.

Table 9
IMPORTANT FACTORS - CRASI - STAGE IV
(CRASI Values - Maximize)

Source Position (inches)	Bismuth Shield (inches)		
	1.75	2.25	2.75
1.0	50.0	50.4	48.8
1.5	49.3	48.8	48.3

Results

The best overall response (considering Cf/f, CRASI, and VISQI) was obtained using Kodak AA film under the following conditions: an air gap of one and one-half inches, a collimator ratio of 14.3 (collimator inlet diameter of 3.5 inches), no moderator gap, source position of one inch off the axis, two and one quarter inches of bismuth shield, and an exposure time of two hours. Figure 10 is a positive print of a neutron radiograph made under the conditions

Figure 10. POSITIVE PRINT OF A NEUTRON RADIOGRAPH.

just listed. It contains a VISQI object, a CRASI object, a 0.020-inch cadmium plate, and polyethylene numbers for identification. This radiograph had a CRASI index of 50.8 percent and a Cf/f ratio of 0.654.

Overall, the improvement made in this facility was quite significant. The number of VISQI faults was slightly reduced from an average of 24.9 to an average of 23.5. This number of VISQI faults could be reduced further by increasing the collimator ratio, but this would adversely affect the Cf/f ratio and CRASI index.

The Cf/f ratio was reduced from an average of 0.820 to an average of 0.658, a 19.8 percent improvement. The CRASI index was increased from an average of 29.6 to an average of 50.4, a 70.3 percent improvement.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be stated as a result of this study:

1. Significant improvements were made for both the Cf/f ratio (film contrast) and the CRASI index (neutron scatter).
2. Considered singly, the number of VISQI faults (radiographic resolution) could be improved further.

It is recommended that the various radiographic parameters be made more flexible (ie, a more variable collimator ratio and more air gap space). A variable-ratio collimator system has been manufactured. This variable-ratio collimator system should be optimized.

BIBLIOGRAPHY

Cochran, W. G. and Cox, G. M.; *Experimental Designs*; John Wiley and Sons, Inc, New York, New York (1968).

Ostle, B.; *Statistics in Research*; Iowa State University Press, Ames, Iowa (1963).

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